PTO 10-5442

WO
19930218
A1
9302888

SYNCHRONOUS LINEAR DRIVE WITH ELECTROMAGNETIC ENERGY TRANSFER
[Synchron-Linearantrieb mit Elektromagnetischer Energieübertragung]

Bernhard Hoffmann et al.

UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. AUGUST 2010
TRANSLATED BY: THE MCELROY TRANSLATION COMPANY

PUBLICATION COUNTRY	(19):	WO
DOCUMENT NUMBER	(11):	9302888
DOCUMENT KIND	(12):	A1
PUBLICATION DATE	(43):	19930218
APPLICATION NUMBER	(21):	PCT/EP92/01804
APPLICATION DATE	(22):	19920807
INTERNATIONAL CLASSIFICATION[5]	(51):	B 60 L 13/02 15/00
PRIORITY COUNTRY	(30):	DE
PRIORITY NUMBER	(30):	P4126454.1
PRIORITY DATE	(30):	19910809
INVENTORS	(72), (75):	Bernard Hoffmann et al.
APPLICANT	(71):	Gründel und Hoffmann Gesellschaft für Elektrotechnische Entwicklungen MBH
DESIGNATED CONTRACTING STATES	(81):	CA, JP, US, European Patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, SE)
TITLE	(54):	SYNCHRONOUS LINEAR DRIVE WITH ELECTROMAGNETIC ENERGY TRANSFER
FOREIGN TITLE	[54A]:	Synchron-Linearantrieb mit Elektromagnetischer Energieübertragung

FOR INFORMATION ONLY

Codes for the identification of PCT contract states on the cover sheets of the documents that publish the international applications in accordance with the PCT.

AT	Austria
AU	Australia
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CS	Czechoslovakia
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
JP	Japan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
LI	Liechtenstein
LK	Sri Lanka
LU	Luxembourg
MC	Monaco
MG	Madagascar
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SK	Slovakia
SN	Senegal
SU	Soviet Union
TD	Chad
TG	Togo
UA	Ukraine
US	United States of America

The invention relates to a synchronous linear drive with a stator designed preferably as long stator /1 arranged at the roadway, with stator coils to create a travelling wave for driving of the moving part, and an exciter part with a direct current-powered exciter winding located preferably on the moving part.

Synchronous linear drives have been known for quite some time (e.g. DE 22 57 773 C2). In such drives the stator is usually designed as a so-called long stator, while the moved part, usually a motor vehicle for transport of persons and/or freight, has an exciter winding into which a direct current is injected. The propulsion takes place by means of the travelling wave generated in the long stator. In this /2* regard, the long stator is divided preferably into sections with multi-phase windings or locally sequential single-phase windings. The power supply to the stator sections takes place by means of rectifiers.

The exciter winding located on the vehicle is powered with direct current.

The configuration described above can also be reversed, so that at the moving part of the stator guide for provision of the travelling wave causing the propulsion and the direct current powered exciter winding is arranged on the roadway [sic; missing phrase in original]. But for a more simple understanding, we shall always assume below that the stator is designed as a fixed-position long stator, and the exciter part is located on the moving vehicle.

The vehicle must be supplied with energy in order to create the exciter field. The energy supply can be provided via a sliding contact, but a contactless energy transfer is preferred.

Different configurations are known for contactless electric energy transfer by means of inductive coupled windings. These energy transfer devices can be viewed as cut-open transformers, and one winding is located on the fixed-position and/or one is located on the moved part. There is necessarily an

---

* [Numbers in right margin indicate pagination of the original text.]

air gap present between the parts moving relative to each other, and this air gap quite obviously causes a deterioration in data values characterizing the power output, compared to a conventional transformer. /3 The primary inductivity for an inductive coupling between the fixed-position and moving part is relatively small, but the leakage inductance is quite large. Therefore, a relatively large reactive energy factor will result.

The expense usually required for a linear drive of the kind under discussion here for a conventional, inductive energy transfer between roadway and moved part is considerable.

The invention is based on the problem of defining a synchronous linear drive of the kind described above in which, with comparatively little additional expense, electric energy can be transferred to the moved part, wherein this energy is to be provided either to create the direct current for the exciter winding, or for additional devices on the moved part or for both purposes.

This problem is solved according to the invention, in a synchronous linear drive of the kind described above, by means such that the alternating current provided to the stator windings and used to generate the propulsion power has a superimposed higher-frequency alternating current and a device arranged on the exciter part for decoupling the energy induced by the higher-frequency alternating current in the exciter coil, or means such that a higher frequency alternating current is superimposed on the direct current provided to the exciter coil, and a device arranged on the stator for decoupling of the energy /4 induced by the higher-frequency alternating current.

The concept of "higher frequency" as used herein means that the frequency of this higher frequency alternating current is significantly greater than the frequency of the alternating current injected to generate the propulsion force. The "higher" frequency, for example, is 10 times greater than the frequency of the alternating propulsion current.

Synchronous linear drives with an exciter coil arranged on the moved part have the property that no propulsion energy supply is needed on the vehicle itself. The energy needed for propulsion of the moved part is provided to the stator coil. Only the energy needed for excitation has to be provided to the exciter winding on the moved part. According to the invention, the basic elements which are provided anyway on a synchronous linear motor are also used for the transfer of energy.

As is known, in a synchronous linear motor, a multi-phase (three-phase) current or several single-phase, mutually phase-offset alternating currents, are needed in the stator and these currents are provided to the winding or windings in order to generate a travelling wave for the propulsion of the vehicle. According to the invention, a higher frequency alternating current is superimposed on this alternating current. It is made available from the devices for injection of the stator current that are /5
already present anyway.

No voltage is induced in the exciter winding by the travelling wave generated for propulsion power. Only the higher frequency alternating current acts like a transformer on the exciter winding. Thus energy can be decoupled from the exciter winding. And as stated, this energy can be used for injection of direct current into the exciter winding, and/or other devices on the vehicle can be powered with the energy decoupled from the exciter winding.

Changes in the induction flux due to the exciter winding are produced in accordance with the higher frequency current fractions.

In the case of a synchronous linear motor according to the invention, the inverter devices which are already present anyway for injection of the stator current, are used as means for injection of the higher frequency alternating current.

If the moved part of the synchronous linear drive, hereinafter also called the "vehicle," is moved along the long stator, then the exciter winding of the vehicle is always located in a new position with

respect to the stator. Thus there will be a periodic coupling between the stator winding and the exciter winding. But the standard synchronous-linear drives are equipped with a multiple phase stator winding anyway, so that the propulsion is effective and uniform in practically any particular position of the /6
vehicle. Therefore, according to the invention it is also possible to obtain an uninterrupted energy transfer along a stator with multiple phase stator windings.

After every movement of the vehicle by a fraction of the pole division of the stator corresponding to the number of phases, there will be an optimum coupling between one phase winding and the exciter winding. Thus at virtually any point in time the transfer of energy is possible over one of the phase windings.

Usually rectifiers are provided for adjusting of the stator current; they will supply individual sections of the stator, depending on the position of the vehicle. According to the invention, these rectifiers are also used for injection of the higher frequency alternating current. As mentioned above, in the case of standard synchronous linear drives, several stator sections are provided so that current is injected solely into those stator sections in which the vehicle is positioned. Now according to the invention, the individual sections are preferably no longer than the exciter section of the moving part (vehicle). If the stator section is much longer than the exciter section, then at the specified maximum reactive energy, the transferred effective power will decrease. A positive energy transfer will be obtained when a single injection of sufficiently short stator sections is ensured, so that the length section not overlapped by the exciter part will have very little effect on the energy transfer. /7

According to the first alternative, then, the higher frequency alternating current is overlapped on the alternative propulsion current. Alternatively, the higher frequency alternating current is overlapped on the direct current injected into the exciter winding, and then the device for decoupling the energy induced via the higher frequency alternating current is arranged on the stator. The exciter winding can

be provided on the route, whereas the stator is located on the vehicle. In the latter case, the means for providing or decoupling of the higher frequency alternating current comprises the power converter unit provided for injection of the exciter current.

It is expedient to provide iron elements in the exciter part to control the magnetic flux. In order to avoid losses due to eddy currents, these iron elements are designed as sheet metal elements, for example.

Proceeding from the fact that a voltage is induced in the exciter winding due to the higher frequency alternating current fraction in the stator, the provided energy must be decoupled from the exciter winding on the vehicle.

In this regard, in a first, passive embodiment the invention provides that a rectifier unit is provided in the exciter part for decoupling, and that if necessary, a servo-element is provided for injection of the exciter direct current. In principle, we are dealing here with a standard rectifier. The reactive energy now needed on the exciter side—due to leakage inductivities on the secondary side and proportional /8
primary inductivity—will be made available on the side of the stator and transferred across the air gap.

It is more efficient to generate the reactive energy needed on the exciter side on the side of the exciter as well. Relative to the construct of the cut-open transformer, this means that reactive power should be generated proportionately on the secondary side in order to minimize the total reactive power fraction. In an extreme case, by taking into account the elevated total reactive power, this reactive power can be generated exclusively on the exciter side. Thus the installation expense along the route can be reduced.

One of these power-generating decoupling devices on the side of the exciter part contains a power converter unit for adjusting of the exciter direct current. In contrast to the passive rectification discussed above, this means an "active" rectification. The power converter unit performs both the rectification of the induced, higher frequency current fraction, and also the adjusting of the direct current which is injected into the exciter winding.

The higher frequency alternating current needed for energy transfer is generated by clock pulses from the rectifier. It should be noted here that the clock pulses generated by the power converter unit are synchronous and in phase with the voltage induced by the stator side.

According to the invention, the injection of the higher frequency alternating current into the stator /9
windings takes place at a phase position reversible by 180°. In the case of a single-phase exciter winding powered by a rectifier, the higher frequency alternating current must act in phase on the exciter winding so that no opposing extinction will occur. At each reversal of pole in the exciter part, the higher frequency alternating current of the stator winding must be rotated in phase by 180°. But then the frequency and phase position of the voltages in the exciter winding are independent of the motion of the vehicle with respect to the stator.

In the exciter winding the higher frequency portions of the stator winding having spatially offset and different phases are additive. Thus a continuous energy transfer will occur.

Basically the effective power to be transferred can be adjusted by appropriate setting of the phase angle between the exciter-side clock frequency and the stator-side clock frequency.

As explained above, the energy transfer takes place in a synchronous linear (motor) by a higher frequency alternating current from the stator to the exciter winding in the moved part (vehicle). In this case, the single windings or multi-phase windings which are present anyway on the stator side are used together with the inverter units belonging to individual stator sections. In addition, separate rectifiers, /10
generators and such can also be provided which are independent of the components provided for the propulsion.

Therefore, due to the invention a power transmission is possible from the stator to the exciter part or vice-versa, wherein preferably the components already provided for propulsion are used.

One sample embodiment of the invention will be explained in greater detail below with reference to /11

the figures. We have:

Figure 1, A schematic illustration of the current path in the stator winding and in the exciter winding of a synchronous linear motor;

Figure 2, A schematic illustration of an exciter part on the vehicle having a synchronous linear drive and also of a stator section located opposite the exciter part;

Figure 3, A fundamental circuit diagram of a synchronous linear motor with a device for inductive injection of energy into the exciter part.

Figure 3 schematically illustrates the arrangement of a synchronous linear drive with a long stator S illustrated in general as being below the dashed line and consisting of several stator sections arranged in sequence, each with a stator winding SA, SB and SC, which in turn are each connected to an inverter WA, WB and WC, respectively. The inverters are powered by a power supply EV via an intermediate circuit ZK. The stator windings of the individual sections are driven by a controller (not illustrated) such that only the stator winding is supplied with current when the exciter winding EE of the vehicle is located above it. In the exciter part the exciter winding EE is connected to a rectifier GE at whose output the energy can be decoupled. This energy is available for various auxiliary devices on the vehicle /12
having the synchronous linear drive. Alternatively or additionally, the energy inductively injected into the exciter winding EE is available as supply energy for the exciter winding.

A direct current is injected into the exciter winding for the excitation. The travelling wave is created by the single winding of the stator, thus here the stator windings SA, SB and SC.

The inverters WA, WB and WC and also the controller (not illustrated) connected thereon cause the generation of a travelling wave but also case a higher frequency alternating current to be superimposed on the alternating current used to generate the travelling wave and having a relatively low frequency. Whereas the lower frequency alternating current is used solely for provision of the energy for the

propulsion power but does not induce any voltage in the exciter winding EE, the higher frequency alternating current part is used to induce a voltage in the exciter winding EE which can be viewed as a secondary winding of a transformer which consists of a stator winding—here, the stator winding SB—and the exciter winding EE and also the air gap located in between.

Figure 1 shows the current profile in the stator winding (lower graph) and in the exciter winding /13
(upper graph). We see that a higher frequency alternating current is superimposed on the lower frequency alternating current which is injected into the individual stator windings for propulsion. This higher frequency alternating current supplies the inductive coupling of energy into the exciter winding. An alternating current is induced there which is adjusted by the fundamental wave of the lower frequency alternating current made available to generate the travelling wave.

Figure 2 schematically illustrates a part of the stator S and the exciter part E. The exciter part is moving to the left in Figure 2, in that a travelling wave is generated in the stator S and a static magnetic field is generated in the exciter part by means of direct current injection.

According to the illustration in Figure 2, a pole E1 on the exciter part is positioned opposite to a pole S2 on the stator. In this area an optimum injection of the higher frequency portion occurs from the stator into the exciter winding. A coupling also occurs between S1 and E2, but it is weaker and only increases with increasing proximity between S1 and E2. Due to position-dependent phase shifting of the higher frequency alternating current used for energy transfer, the result attained is that an in-phase alternating current is always induced in the exciter winding and thus the fractions from the individual area are additive. /14

The elements illustrated in Figure 2 are present anyway in a standard synchronous linear motor.

In a modified embodiment of the invention, in addition to the elements already present anyway in a synchronous linear motor, additional windings can be provided, in particular windings on the exciter part.

The rectifier GE illustrated schematically in Figure 3 is used as a so-called active rectifier. In addition to the function of rectifying the higher frequency alternating current induced in the exciter winding, the rectifier has the additional function of adjusting the direct current to be provided to the exciter winding. Due to corresponding adjusting of the energy flux, a reversed energy transfer can also be attained, that is, the transfer of energy from exciter part E into the stator S.

In an additional embodiment of the invention, the conditions explained above and sketched in Figure 3 are reversed: The "stator" is located on the vehicle, whereas the exciter windings are located on the route. Then the travelling wave is generated on the vehicle.

Claims /15

1. Synchronous linear drive with a stator designed preferably as long stator arranged at the roadway, with stator coils to create a travelling wave for driving of the moving part, and an exciter part with direct current-powered exciter winding located preferably on the moving part,

characterized by means (WA, WB, WC) such that the alternating current provided to the stator windings (SA, SB, SC) and used to generate the propulsion power has a superimposed higher-frequency alternating current and a device (GE, T) arranged on the exciter part for decoupling the energy induced by the higher-frequency alternating current in the exciter coil, or means such that a higher frequency alternating current is superimposed on the direct current injected into the exciter coil, and a device arranged on the stator for decoupling of the energy induced by the higher-frequency alternating current.

2. Synchronous linear drive according to Claim 1, in which the means for providing or for decoupling of the higher frequency alternating current comprise the alternating current unit (WA, WB, WC) used for supplying stator current.

3. Synchronous linear drive according to Claim 1, in which the means for injection or for decoupling of the higher frequency alternating current comprise the pulse power converter unit used for providing of the exciter current.

4. Synchronous linear drive according to Claims 1, 2 or 3, in which current is injected into the /16
stator at sections where the exciter winding (EE) is located, wherein the individual sections (SA, SB, SC) are preferably sufficiently short so that the length section not overlapped by the exciter part has very little effect on the energy transfer.

5. Synchronous linear drive according to one of Claims 1-4, characterized in that the energy induced in the exciter winding (EE) by the higher frequency alternating current is used for direct current injection to the exciter winding (EE).

6. Synchronous linear drive according to one of Claims 1-5, characterized in that the energy induced in the exciter winding by the higher frequency alternating current is used to power auxiliary devices arranged on the moved part.

7. Synchronous linear drive according to Claims 1 and 3, characterized in that the energy induced in the stator by the higher frequency alternating current is used to generate a travelling wave current.

8. Synchronous linear drive according to Claims 1-7, characterized in that a rectifier unit (GE) is /17
provided in the exciter part for decoupling, and that a servo-element is used to provide the exciter direct current.

9. Synchronous linear drive according to one of Claims 1-7, characterized in that for decoupling, a pulse current rectifier is provided in the exciter part which rectifies the higher frequency induced power fraction and adjusts the direct current for the exciter winding.

10. Synchronous linear drive according to one of Claims 1-9, characterized in that the supply of the higher frequency alternating current into the stator windings (SA, SB, SC) takes place at a 180° phase shift.

11. Synchronous linear drive according to one of Claims 1-10, characterized in that the decoupling device is connected to the exciter coil.

12. Synchronous linear drive according to one of Claims 1-10, characterized in that additional windings for inductive energy transfer are arranged in the exciter part. /18

13. Synchronous linear drive according to one of Claims 1-12, characterized in that additional power injection and coupling devices are provided on the stator for energy transfer.

1/1

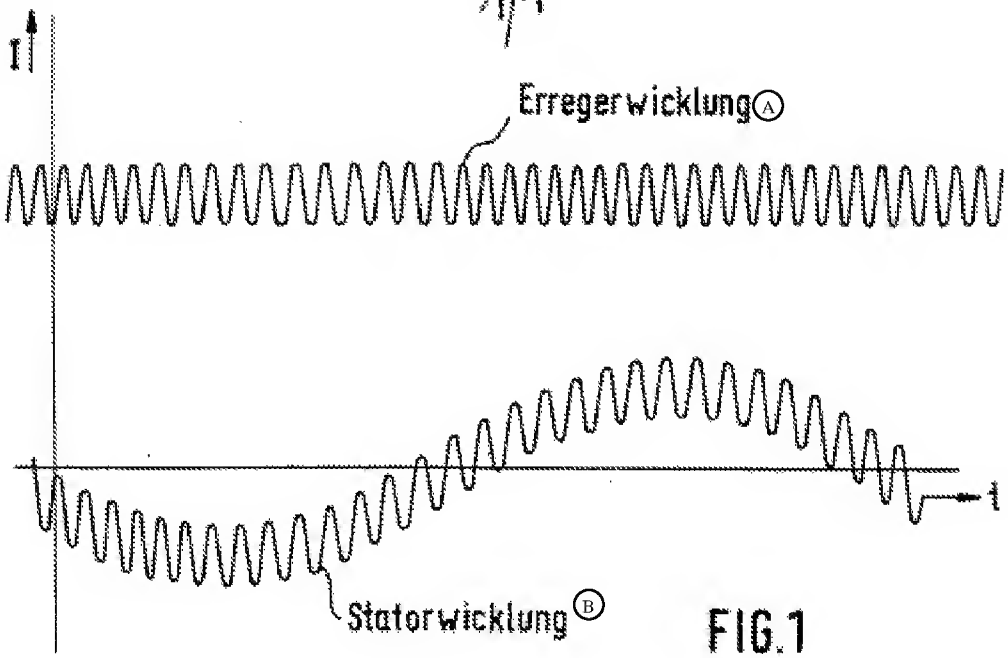

FIG.1

Key: A Exciter winding

B Stator winding

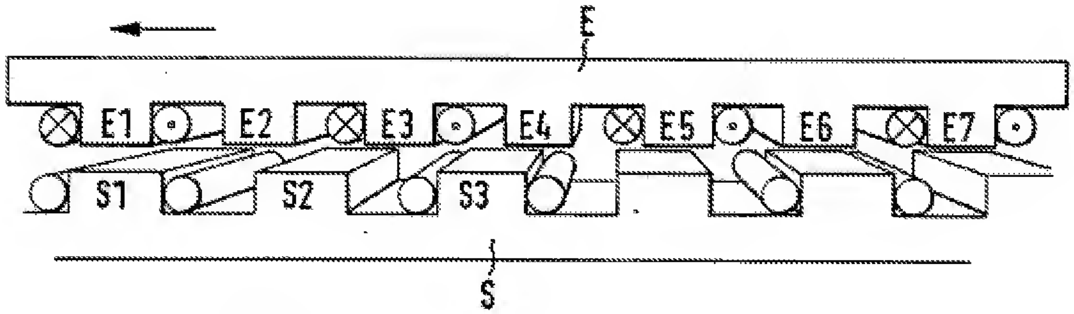

FIG.2

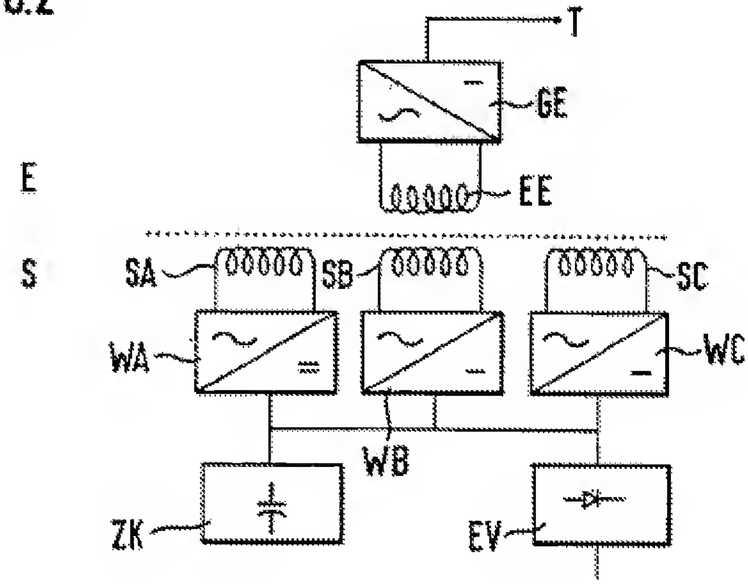

FIG.3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/ EP 92/01804

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl.5 B60L13/02; B60L15/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl.5 B60L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	IEEE TRANSACTIONS ON MAGNETICS Vol. 28, No. 1, January 1992, NEW YORK US pages 474 - 477, XP000258042 M.SHIBATA ET AL. 'On-Board Power Supply System of a Magnetically Levitated Vehicle' see the whole document ----	1
A	DE, A, 2 257 773 (WEH HERBERT) 30 May 1974 cited in the application see page 12 - page 13 ----	1
A	DE, A, 2 423 579 (SIEMENS AG) 27 November 1975 see page 4 - page 8 ----	1,6

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 October 1992 (01.10.92)	27 October 1992 (27.10.92)

Name and mailing address of the ISA/	Authorized officer
EUROPEAN PATENT OFFICE	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP 92/01804

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JOURNAL OF THE INSTITUTION OF ELECTRICAL ENGINEERS Vol. 121, No. 11R, November 1974, STEVENAGE GB pages 1224 - 1248 A.J.ELLISON ET AL. 'Surface-guided transport systems of the future' see page 1238, paragraph 5.2 see page 1240, paragraph 6 -------	1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. EP 9201804
SA 63096

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 01/10/92
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-A-2257773	30-05-74	None	
DE-A-2423579	27-11-75	None	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82